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ABSTRACT

Detailed are the highlights of the history and technology of crude oil and its end products. Included also are some of the important programs that American industry and the Federal government are planning and undertaking in order to enhance the benefits of oil and make use of the limited available quantities as wisely as possible, both now and in the future. A bibliography of additional books and articles on petroleum is included. (BT)

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FOSSIL ENERGY

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Oil

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2

ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION

Oil

by William W. Eaton

Contents

Chapter 1 Introduction 2

Chapter 2 Origin and Nature 8

Chapter 3 History 12

Chapter 4 Technology 20
- Exploration and Prospecting 20
- Drilling 24
- Offshore Drilling 28
- Refining and Purification 30
- Petrochemicals 35
- Transportation 40

Chapter 5 Looking Ahead 48

Chapter 6 New Programs 56
- Enhanced Recovery 57
- Oil From Shale 59

Bibliography 63

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Chapter 1. Introduction

The term petroleum has sometimes been used technically in a broad sense to include gas, liquid, and solid materials. But the more frequent practice—and the one followed in this booklet—is to use the word to refer only to the liquid, or crude oil, phase.

The annual world output of crude oil is now about 20 billion barrels of 160 liters (42 gallons)* each, which amounts to well over 757 liters (200 gallons) for every person on the earth each year. An impressive 30% of this total is consumed in the United States at the rate of over 4160 liters (1100 gallons) per American per year!

At this moment in history, there seems to be no other single commodity more important to man—economically, politically, or technically—than petroleum. Through its

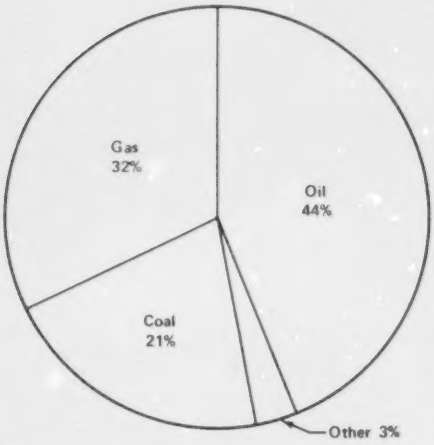
*In this book, metric units are given first followed by American units in parentheses. For example, 1000 square kilometers (400 square miles). Please note that all the units have in general been rounded off to the same number of significant figures.

many important applications as an energy source and its unique potential for originating thousands of petrochemicals, petroleum has probably had a greater overall usefulness to mankind than any other material ever found in nature, except the air, water, and land of the earth itself.

The chart on page 4 shows that 44% of total U.S. energy resources consumed in 1975 were petroleum and its products. The chart on page 5 reveals that, in addition to the important fuel applications in industry and for residential and commercial uses, well over half the petroleum consumed in our country is burned for transportation by automobiles, airplanes, trains, and ships. At present, there are no satisfactory substitute energy sources for most of these transportation applications.

Petroleum is now the source of more than 80% of the country's organic chemical products, including such valuable substances as plastics, synthetic textile fibers, detergents, fertilizers, insecticides, drugs, and hundreds of other useful products. And it is estimated that after 15 to 20 years, more than 98% of all organic chemicals will originate with crude oil.

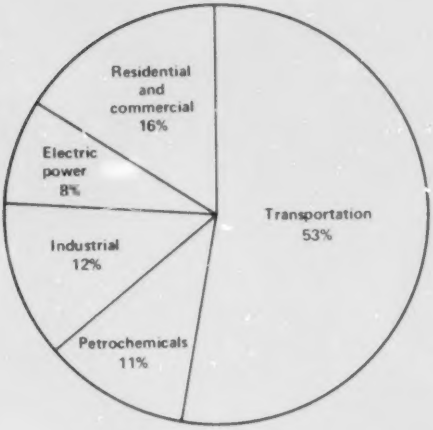
U. S. ENERGY CONSUMED
1975



Without an adequate continuing supply of crude oil, this country—and much of the rest of the developed world as well—would literally come to a stop and suffer very serious economic, social, and financial consequences.

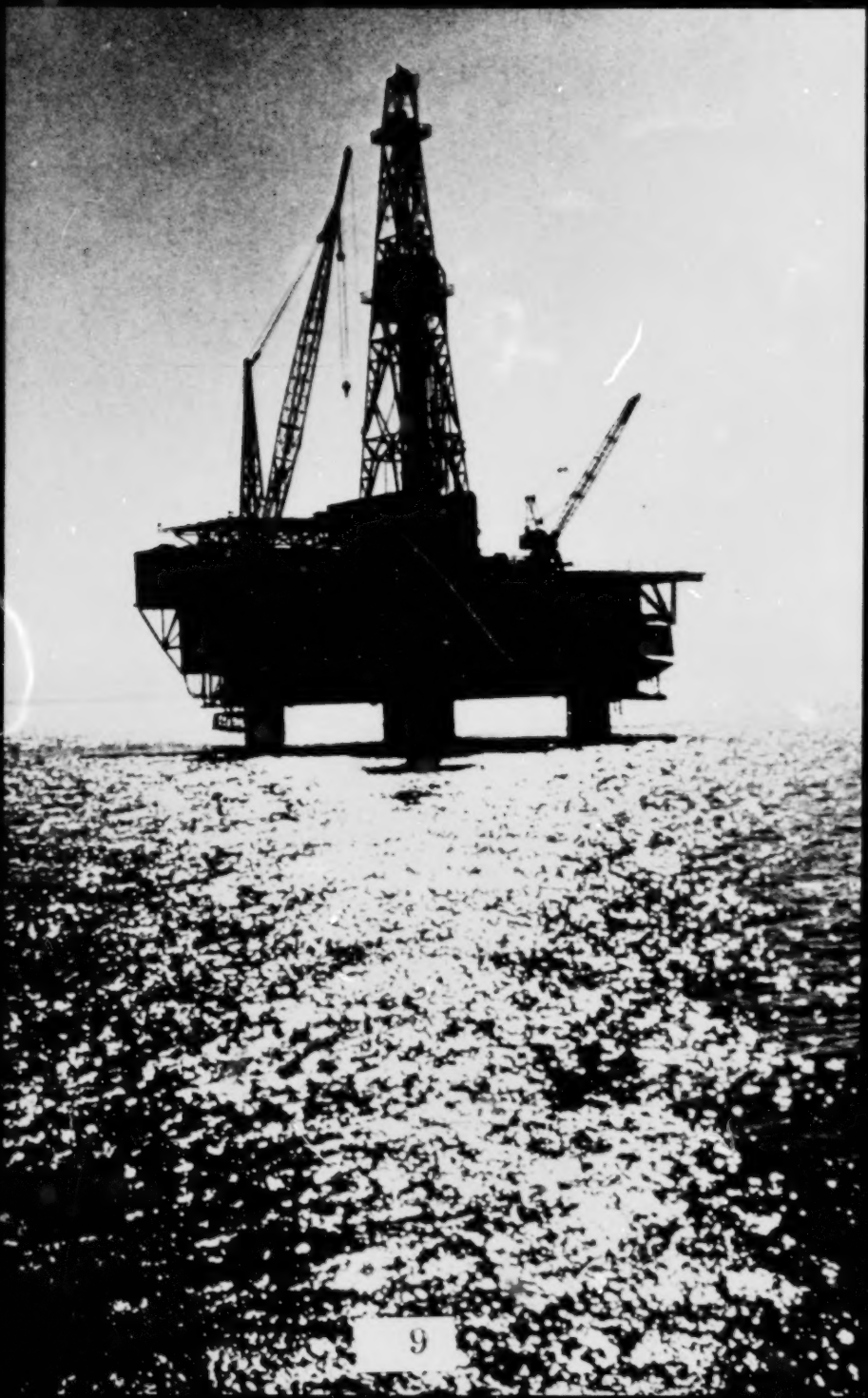
This booklet covers a few of the highlights of the exciting history and technology of crude oil and its many end products. Included also are outlines of some of the important programs that U.S. industry and the Federal Government are planning and undertaking in order to enhance the benefits of oil and make use of the limited available quantities as wisely as possible, both now and in the future. The Energy Research and Development Administration (ERDA) is the key federal agency in the coordination of these efforts.

U. S. OIL USES
1975



The story of the discovery, production, and use of crude oil is one of the most intriguing in the history of the human race. For those wishing more details than can be included in this brief account, there is a bibliography on page 63 that will be helpful for further reading.

Offshore oil-drilling platforms, such as this one, can drill wells in water 305 meters (1000 feet) deep and have living quarters for more than 50 men.



Chapter 2.
Origin and Nature

It is strange, indeed, that such a physically unpleasant natural substance as petroleum should have become in recent years one of the most precious source materials on earth. It is also surprising that, with all the scientific knowledge of our modern times, we still do not fully understand exactly how these varied and valuable mixtures of organic compounds that comprise petroleum, or crude oil, were formed.

Early scientists classified petroleum as a mineral produced within the earth. But the consensus of opinion now is that petroleum is of organic origin and was formed initially hundreds of millions of years ago from the decomposition of various kinds of plant or animal life. The sedimented (or settled) substances and silt and sand were chemically changed, through the action of heat and tremendous pressure within the earth over millions of centuries, to produce petroleum.

Whatever the complex mechanism of formation, it seems clear that a very unusual set of circumstances was required. This helps to explain why the occurrence of petroleum is relatively rare—far less common than coal, another fossil substance that appears to have had a somewhat different origin.

As found in nature, petroleum consists of a mixture of a large number of complex organic chemicals known as hydrocarbons. These compounds contain the basic elements of hydrogen and carbon in various proportions and are sometimes combined with other elements such as sulfur, nitrogen, and oxygen. The great potential usefulness of petroleum is based on the fact that hydrocarbons are in effect the parent substances from which are derived almost all other organic compounds, which have so many different valuable applications for man.

Depending on where it is found, petroleum varies considerably in physical appearance and other characteristics. Although basically a liquid containing gaseous and solid components, its consistency may be as thin as kerosine or as thick as tar.

When large quantities of gaseous compounds are contained in petroleum, it is usually associated with a deposit of natural gas, another related fossil substance of obscure organic origin. When large quantities of solids are present, the mixture is thick and viscous and is called asphalt, or bitumen.

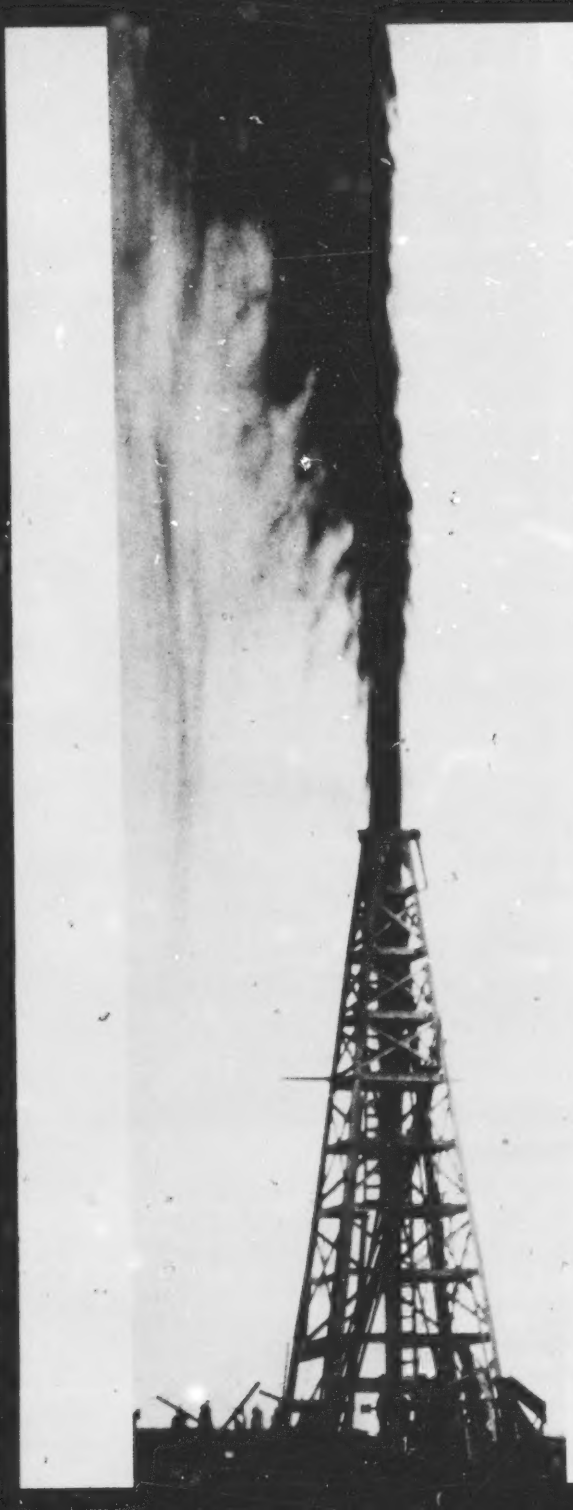
Petroleum deposits are found mostly in sedimentary rocks that were formed aeons ago by sedimentation of sand, silt, etc., often in seawater.

Strictly speaking, petroleum is never found in a large underground pool (even though this term is often used) but rather loosely dispersed under pressure in porous rocks over a wide area.

When a well is drilled into the oil-bearing layers of rock, the pressure on the trapped gas and oil forces a portion of either one or both to the surface. If the well is drilled near the top of the gas and oil layers, only gas will rise to the surface. While the fraction of the trapped oil that can be recovered in properly drilled and operated wells varies, the national average is about one-third. Specialized techniques, described in Chapter 6, are being developed to recover some of the remaining oil.

The Spindletop Well near Beaumont, Texas, which came in on January 10, 1901, proved the feasibility of drilling in salt domes in flat country, opened up Texas as a major producing area, and showed that the oil industry could produce in quantities hitherto undreamed of. The plume rose 30.5 meters (100 feet) above the derrick and the well flowed at the rate of 100,000 barrels a day. It was finally capped after 9 days with a unique invention called a "Christmas tree"; this is a wellhead valve assembly for controlling pressure and flow, which ended the tremendous waste of uncontrolled gushers.

12



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Chapter 3.
History

Petroleum deposits that have spontaneously come to the surface of the earth through natural forces have been known to mankind for thousands of years.

Archaeological evidence indicates that in ancient Persia (now Iran) and Mesopotamia (now Iraq), a form of asphalt, sometimes called bitumen, or pitch, was used for medicinal purposes and as a bonding material instead of mortar. It was also widely used to caulk ships, including Noah's Ark according to certain versions of the story of the Great Flood.

In the 5th century B.C. the famous Greek historian, Herodotus, described how natural oil and asphalt were used. In fact, the use of petroleum seepages seems to be traceable back to 3000 B.C., when man may have employed natural forms of asphalt for various purposes.

The axles of Pharaoh's chariots in ancient Egypt were undoubtedly lubricated by a crude petroleum of some kind. And Alexander the Great, among others, is supposed to have used burning petroleum to frighten the war elephants of his enemies!

In early Christian days, the Arabs developed crude methods for distilling petroleum to produce various products for lighting, cleaning textiles, and medicinal uses. These techniques were later introduced into Spain and other parts of Western Europe.

In China, as early as the 3rd century A.D., oil was discovered accidentally while drilling for salt. By the 12th century, there were wells in China 910 meters (3000 feet) deep.

On one of his famous trips through Persia in the years 1271 to 1273, Marco Polo recorded the early commercial development of the oil fields of the Baku peninsula on the Caspian Sea in what is now the U.S.S.R. The ancient "eternal fires" of this area were probably due to natural gas seepages ignited by lightning in prehistoric times. They were the basis for the primitive religious cults of fire worshippers. More recently, this territory has become one of the world's greatest oil-producing regions.

In the mid-19th century, relatively limited quantities of liquid fuels were being regularly produced in many countries, mainly for illumination and cooking, by the simple distillation of naturally occurring petroleum or asphalt.

During this same period, and as early as 1840, the United States actually experienced

Edwin L. Drake.

its first oil "shortage", in this case, whale oil, which was the best available illuminant as well as a good lubricant. Although there were 700 American ships in the whaling fleet, prices rose to $2.50 a gallon as demand increased and the world supply dwindled.

In order to meet the crisis, other substitute oils were developed in the form of turpentine derivatives, lard oil, and another type of kerosine, called coal oil, made from soft cannel coal.

This was the situation in 1859 at the time of the most important single event in the history of U.S. petroleum—the drilling of the first oil well, the Drake Well, at Titusville in northwestern Pennsylvania, where petroleum was found at a depth of only 21 meters (69 feet).

Although the famous Drake Well was shallow compared with more modern depths of many thousands of feet, it yielded far more crude oil than anyone had ever seen before. Edwin L. Drake and his well-driller, a blacksmith named W. A. "Uncle Billy" Smith, had been fortunate enough to tap a small portion of a much larger deposit of petroleum along Oil Creek, which got its name from the oil seepages that could be skimmed from its surface.

W. A. Smith

Soon hundreds of wells were being drilled in this area, as part of the feverish excitement generated by the sudden easy availability of oil in a society with a constantly increasing demand for it. Thus the petroleum industry was born, and the oil shortage was over for the time being.

In this 1861 photograph, Edwin L. Drake (top hat and beard) and Peter Wilson, a Titusville druggist who encouraged Drake in his venture, stand next to the world's first commercial oil well.

Throughout the latter part of the 19th century, the most important developments in the petroleum industry occurred in the United States and the U.S.S.R. These two nations accounted for 90% of the world's crude oil output at the beginning of the 20th century.

Oil in commercial quantities was also discovered and exploited in the late 1800s in

such widely separated areas as the Dutch East Indies, Rumania, and Venezuela (where it is said that a barrel of crude oil was sent to Spain as early as 1539). In the Middle East, serious commercial oil exploration and recovery activities began around the turn of the 20th century, especially in what are now the countries of Iran, Saudi Arabia, and Kuwait. This geographical area now appears to possess the world's largest petroleum reserves.

Early in the 20th century, another severe petroleum shortage developed in the United States, mainly because of the constantly expanding market for gasoline, which is refined from petroleum. This strong demand was generated almost entirely by the dramatic increase in the number of automobiles powered mostly by gasoline engines.

From 1903 to 1908, the number of "horseless carriages" multiplied almost five times and then doubled again between 1909 and 1911. One natural result was a real gasoline shortage, because the production of crude oil from which the gasoline was refined simply did not keep up with demand. An additional important factor was that the refining processes had a relatively low overall efficiency in the range of 15% to 18%.

The powerful incentive caused by this shortage stimulated additional scientific research, which resulted in the development in 1913 of the so-called "cracking" process by which the yield of gasoline refined from crude oil was doubled. (See Chapter 4.) The invention of this ingenious chemical procedure averted a serious continuing deficiency in

gasoline supplies and helped establish a sound basis for the automotive and aircraft industries as well as many other vital industrial and military activities.

Between World Wars I and II, many improvements were made in techniques for locating, recovering, and refining petroleum. Consequently, gasoline production increased enormously. The economy of all technologically developed countries was rapidly and steadily adapted to take advantage of the innumerable convenient applications of gasoline and diesel engines. The production of petroleum continued to increase sharply. During just one decade, 1937 to 1947, which included World War II, more petroleum was

Sign on a horse-drawn oil tank wagon about the turn of the century.

produced in the world than had been taken from the ground in all previous history.

Such rapid production naturally worked in the direction of exhausting many of the known deposits of petroleum, and geologists were thus stimulated to develop new and improved methods of prospecting for oil. (See Chapter 4.) But after World War II, even though the demand for petroleum and its products continued to increase, the rate of discovery of new wells began to drop.

To reverse this trend, many new techniques were tried and are still being developed to make more oil available. (See Chapters 4 and 6.) A further response to dwindling petroleum supplies is the attempt to produce liquid fuels from coal, another natural fossil fuel similar in many ways to petroleum and more plentiful in the United States than in any other part of the world.

The more recent spectacular development in the history of petroleum utilization has been the phenomenal growth, mainly since World War II, of a giant petrochemical industry that now annually produces billions of dollars worth of a variety of synthetic chemicals and useful substances derived chemically from petroleum.

One of the most striking early examples of such a vital material was synthetic rubber, which was developed for the first time in commercial quantities during World War II in a frantic rush to fulfill wartime requirements. This valuable commodity, much superior to natural rubber for most applications, has been produced in ever-increasing quantities and

now accounts for over three-fourths of all new rubber used by industry.

In a somewhat different and specialized area of application—lubrication—petroleum derivatives have always played a vital role during the entire history of the development of complex machinery and engines. Literally hundreds of millions of our machines and engines, most notably, automobiles, now depend for efficient operation on specially designed lubricants refined from petroleum.

It is difficult to realize in retrospect that most of the exciting history of the development and use of such an important natural resource as crude oil has taken place in just a little over 100 years. Unfortunately, during this period of time, and particularly during the last 50 years, a substantial fraction of the world's recoverable crude oil supplies have been used up. New developments, such as additional petroleum fields, more complete recovery from known deposits, or the development of satisfactory substitutes, will have a most profound effect on a world that now depends so critically on the end products of petroleum for its quality of life. (This question is discussed in more detail in Chapter 5.)

Chapter 4. Technology

Exploration and Prospecting

There are no physical or chemical characteristics of petroleum that enable underground deposits to be specifically pinpointed from the surface of the earth. Therefore, prospecting techniques to locate new fields cannot be expected to provide a reliable forecast of the occurrence of petroleum, and so most exploration has been undertaken in those areas that have already produced oil.

The various prospecting methods now in use, while highly sophisticated from a scientific point of view, furnish at best only an indication of the chance of finding petroleum in a given spot. The final test of the existence of oil is to drill into the earth.

In the very early days of oil prospecting, wells were drilled mainly at or near the location of surface seepages. Later, because of

the tremendous value of the discovered oil, "wildcat" wells were drilled on a purely speculative basis with little specific evidence of the existence of petroleum in the area. A number of productive oil fields were accidentally discovered in this manner, although in more recent years only about 10% to 15% of wildcat wells have been successful.

Scientific exploration methods were not developed until early in the 20th century. Since that time these techniques have been steadily improved and extended to such a degree that oil prospecting, even though limited in accuracy, has become a well-developed and mature science, with a number of different basic approaches.

One of the earlier techniques was simply a careful mapping of the land and associated geologic features, including outcropping of the types of rock known to be associated with petroleum deposits. Later on, more elaborate geophysical techniques based on magnetic, gravity, and seismic (shock wave) measurements were increasingly developed and used successfully for oil exploration.

The magnetic methods are related to the fact that the strength of the magnetic forces—the kind that move a compass needle—at various locations on the earth's surface may be an indication of the types of rocks underground. Careful measurement and mapping of these forces may provide a hint as to the presence of subsurface oil-bearing rock. A magnetometer, used to measure magnetic intensities, can even be trailed from a low-flying airplane to provide a large quantity of data in a short time.

Above, a crew prepares explosive charge apparatus underwater. Below, another exploration crew sets off an explosive charge. In both cases, shock waves will be recorded by a seismograph. This information will provide an indication of whether oil-bearing formations are underground.

In the gravity technique very sensitive instruments are used to measure minute variations in the pull of gravity at different locations. Such information enables lines of equal gravity force to be plotted in a manner similar to the lines of equal temperature or pressure on the familiar weather map. In many instances the types of underground geologic formations, such as salt domes, indicated by gravity maps of this kind, may provide valuable clues regarding the existence of petroleum.

The seismic, or shock wave, technique involves the initiation of a small controlled explosion, near the earth's surface, and a very careful measurement of what happens to the resulting underground sound waves as they travel through the earth. Such waves are reflected and in some cases refracted, or bent, in many different ways by the various underground layers of rock and other subsurface materials. Although this method requires complex instruments and equipment, as well as skilled interpretation of the data, it has been used very extensively with considerable success all over the world.

While a well is being drilled, it is possible to obtain further valuable information about underground conditions by examining the material brought up as the cutting tool proceeds downward. After the well is completed, additional useful data can be obtained by lowering into the well a special miniature package of electrical instruments to measure many characteristics, such as temperature, conductivity, radioactivity, etc., at different levels. A record of the readings of these

instruments, at various depths below the surface, is called a "well log", and the technique is called "well logging". Much valuable information about subsurface characteristics may be obtained in this manner.

Oil prospecting is still not an exact science, even with all the complex technical equipment and ingenious methods employed. This explains why well drilling, as described below, is a frustrating and often financially ruinous activity.

Drilling

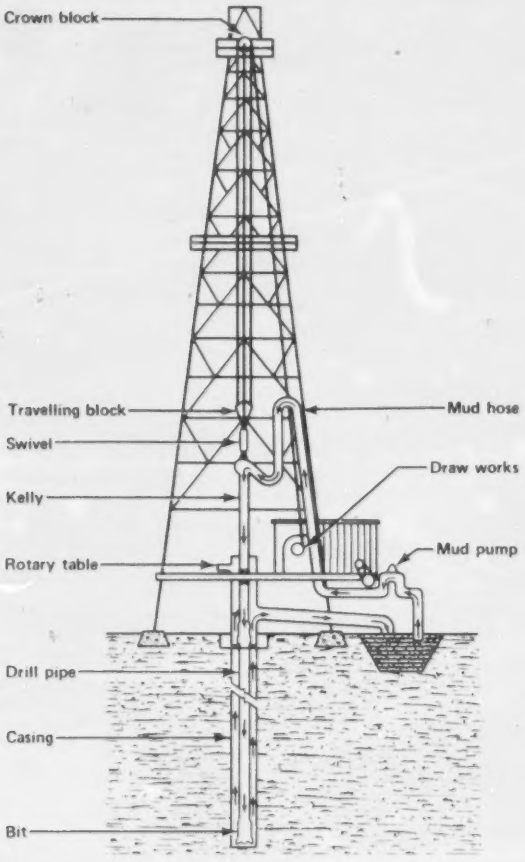
Drilling for oil is a complicated expensive venture requiring large capital investment. The rotary cutting method now used most extensively for drilling deep wells involves thousands of feet of well casing and drill pipe, a derrick, a substantial power source, drill bits, and drilling muds and chemicals. A team of several men working over a period of many weeks or months is needed to operate the equipment.

As the drill bit rotates and cuts into rock and other material, the cuttings are removed continuously by a circulating mud slurry pumped down inside the drill pipe, and returned to the surface in the space between the pipe and the casing.

The pressure of this drilling mud helps prevent the collapse of the hole and the

Even with the aid of scientific knowledge, the only way to find oil is to dig for it. As a well gets deeper, new sections are added to the pipe string that turns the drill bit.

ROTARY DRILLING RIG



entrance of water at various levels. In some instances, a steel casing may be needed to seal the well down to where the drill is cutting.

The drill cuttings are allowed to settle from the drilling mud at the surface and special chemicals are usually added before it is recycled down into the well, where it cools and lubricates the drill bit and maintains the

desired pressure. Diesel engines are the usual source of power in modern drill rigs.

If an oil-bearing formation is reached, the well usually will have to be cased and sealed by cementing so that the oil can be pumped to the surface satisfactorily. In cases where the oil flows up freely under pressure, pumps are not required.

The large basic costs required for oil well drilling have been climbing in recent years, although drilling techniques that are faster and more efficient have partially compensated for these inflationary increases. At the current average of $15 to $20* per foot of depth, the typical 1200- to 1500-meter (4000- to 5000-foot) well now costs as much as $100,000.* Deeper wells have been successfully drilled down to 9100 meters (30,000 feet) and more, but much higher expenditures, often millions of dollars, are required.

In developing countries, in remote areas, and in any location where drilling must be performed under difficult environmental conditions, overall drilling costs may rise drastically. The necessity to provide for proper housing, utilities, and other needs in such areas may run up the bill for a few wells to many millions of dollars.

The inherent financial risks involved in oil drilling are illustrated by data for a recent typical time period (6 months) when 16,000 wells were drilled in the United States in previously established oil fields, and one-fourth of these were "dry", or unproductive. Five thousand wells were drilled during this

*1975 dollars.

same period in new and unexplored territory, and 87% of these were dry.

Offshore Drilling

Many years ago oil-producing reservoirs were discovered under the sea, just off the coast of such states as California and Louisiana. These deposits were successfully tapped, and this marked the beginning of a large offshore drilling activity in lakes, bays, and shallow coastal waters all over the world.

Offshore wells are drilled either from floating platform rigs or from fixed platforms, first floated into place and then allowed to settle on the bottom. This costly, man-made island contains, in addition to the well-drilling equipment, elaborate provisions for living quarters, power, and often a helicopter landing pad.

The principal areas in which offshore drilling operations have been undertaken are in Lake Maracaibo (Venezuela), the Gulf of Mexico, the Caspian Sea (Russia), the Persian Gulf (Middle East), and in other offshore regions close to Trinidad, Libya, Egypt, West Africa, Malaysia, and Japan. Recently the bottom of the North Sea has been extensively explored for oil with considerable success. One of the latest offshore drilling platforms to be installed in these waters established many remarkable new records and illustrates vividly the advanced state of development of this technology.

The "Condeep Brent B" shown on page 29 as it was towed out to sea, extends 80

The Condeep "Brent B", one of the largest oil platforms ever built, heads down the fjord from Stavanger, Norway, towed by 5 tugs totalling 70,000 horsepower.

meters (263 feet) below the water line, and is one of the largest and most expensive ($220 million) oil platforms ever built. Measuring 248 meters (813 feet) from bottom to top, it is higher than most tall buildings. When sunk into place on the sea bottom, it will stand in 140 meters (460 feet) of water with 108 meters (353 feet) still above the water's surface.

By all indications, there are tremendous quantities of oil that could be recovered by offshore drilling. However, the whole question of conducting such operations off the Atlantic coast of the United States has become a highly controversial subject, because

on the one hand there is potential damage to the environment, and on the other, the drastic need for energy on the East Coast.

Refining and Purification

Petroleum refining refers to the series of complex physical and chemical processes by which the crude oil, as taken from the ground, is separated into its various components, or "fractions", which may in later stages be recombined or chemically altered to yield the desired products for final consumption.

Originally, refining operations were restricted to the selective distillation of the many different hydrocarbon chemical substances that make up crude oil. These boil off at various charaeteristic temperatures, and can then be collected separately by condensing them to liquids. A typical fractionating tower, indicating how some of the principal end products are drawn off at various temperatures, is shown in the illustration on page 31.

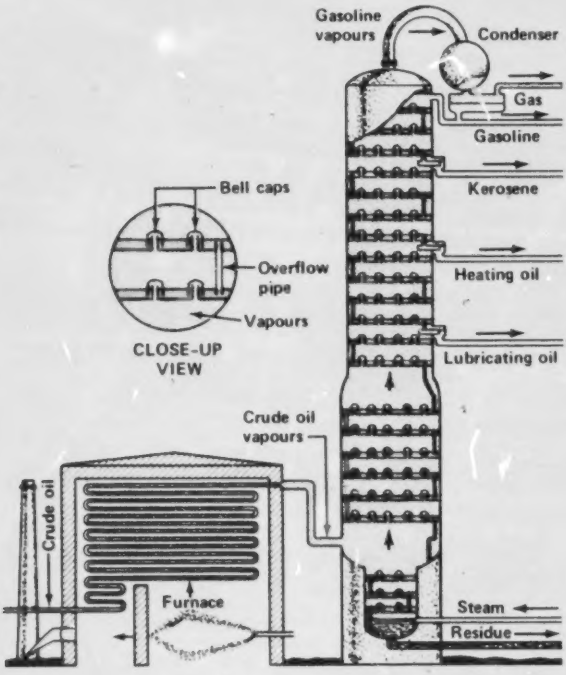
Solvent extraction is another technique that has been used to selectively dissolve out the various desired products. These are then recovered in separate operations by which the solvents are boiled off for further use in additional cycles.

The more complex and efficient methods of refining oil involve the alteration of the hydrocarbon molecules, which are the basic building blocks of the various compounds. These molecules, consisting mainly of atoms of the chemical elements carbon and hydrogen, exist in chains, rings, or other groupings.

The exact structure and composition determine the properties of each specific material.

The series of intricate chemical processes that constitute oil refining include the breakdown of the larger hydrocarbon molecules (cracking), the recombination of smaller molecules into larger ones (polymerizing), the changing of the internal molecular structure (reforming), and purification.

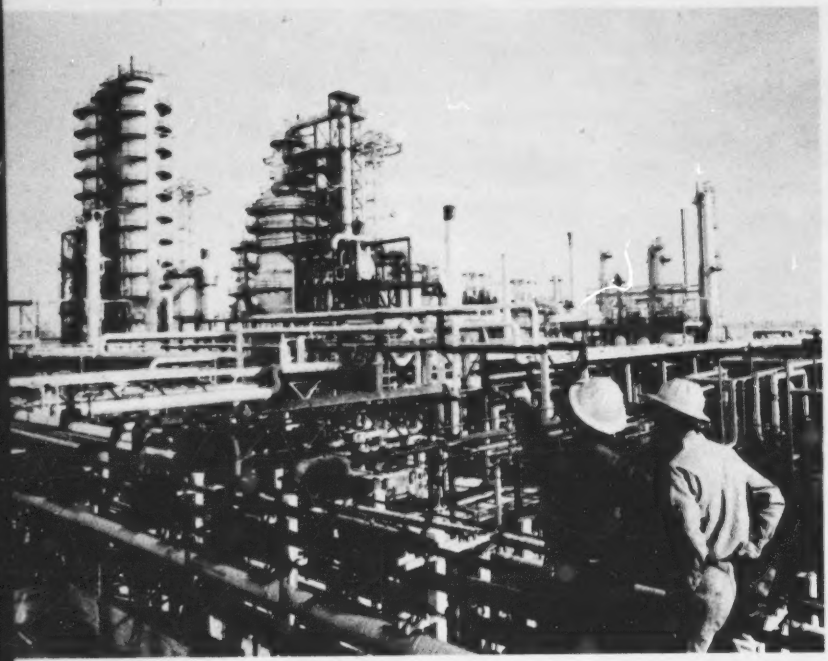
The thermal cracking processes, first introduced in the United States in 1913, in-



A fractionating tower used for petroleum distillation.

volved high pressures as well as high temperatures. It was later discovered that certain special compounds, called "catalysts", were able, although they were not used up in the reaction, to greatly increase the rate and alter the nature of the cracking processes. The most important result of the use of both thermal and catalytic cracking techniques was the significant improvement in the yield and quality of the gasoline produced.

A seemingly endless maze of pipes is characteristic of the modern petroleum refinery. The tall catalytic cracking units ("cats") are in the center. The big "cats"—some as tall as a 20-story building—can process more than 100,000 barrels of oil a day.



Polymerizing may be considered the reverse of cracking, because relatively smaller and lighter molecules are combined under proper conditions to form larger molecules with desired properties.

The type of chemical processing that actually alters the internal structure of the hydrocarbon molecules is called "reforming". In refineries, it is usually undertaken with lower grade gasoline stocks produced by simple distillation. The main objective is to improve the useful characteristics of the final product.

One of the most important aims of refinery technologists in the first half of the 20th century was to improve the quality of gasoline, and this led directly to the development and commercialization of the methods outlined above. These successes, in turn, made possible dramatic increases in the use of internal combustion engines for automobiles, trucks, airplanes, and farm machinery, and contributed greatly to the quality of life in the United States and around the world.

An outstanding example of gasoline improvement through the years is the increase in octane rating, which is the most important single measure of the combustion characteristics of gasoline. Based on an arbitrary scale of 0 to 100, the octane rating of 50 for most gasoline in 1920 increased to about 90 in 1970 with even higher values available for premium grades.

The increase in octane number during this half-century permitted the use of constantly higher compression ratios in automobile engines and this led to better efficiencies.

During this period, the overall performance of automobile engines more than doubled, on the average, under comparable controlled conditions.

Purification is another important process carried out in petroleum refineries. It consists mainly of the removal of sulfur, nitrogen, or other unwanted components. This part of the total operation has in recent years been given a higher priority, largely because of the greater emphasis now placed by society on achieving a clean environment.

Such a policy was formally established by the National Environmental Policy Act of 1969, which led to the creation of the Environmental Protection Agency (EPA), an independent agency of the Federal Government that has the power to formulate and enforce regulations governing pollution.

Crude oil from certain producing fields contains sufficient impurities (mainly sulfur) so that burning the fuel products derived from such petroleum becomes environmentally unacceptable, at least in terms of the latest regulations. It is also desirable for other reasons to remove the sulfur from petroleum fuels, because it increases wear and maintenance problems and limits the effectiveness of anti-knock additives. For all these reasons, purification techniques, which unfortunately are complex and expensive, have been developed.

A successful method using copper oxide to "sweeten" (as the process is popularly known) the so-called "sour" crude was invented many years ago. This technique laid

the groundwork for many other methods now employed in refineries to eliminate impurities or to change corrosive or foul substances into harmless and odorless materials. For reasons of cost, the tendency in today's refinery technology is to desulfurize the various fuels or other end products during, rather than after, manufacture, so that the purification steps have become an established part of the whole refinery process.

Refining operations in the United States have grown impressively through the years in volume as well as efficiency. Between 1920 and 1970 the total annual refinery output multiplied by a factor of almost 10—from 362 million to 3½ billion barrels. There are now over 250 refineries in the United States, which process more than one-fourth of all the world's crude oil.

The major job of petroleum refineries has been to produce large quantities of high quality fuels, lubricants, and related products. However, the elaborate chemical processing first developed in refineries has been extended to produce a wealth of other types of products called petrochemicals.

Petrochemicals

Petrochemicals, as the name suggests, are simply the many different chemicals derived from petroleum; these do not include the products that are used primarily as fuels, such as gasoline, kerosine, jet fuel, heating oils, etc. The term petrochemicals includes a whole range of organic (and a few inorganic) chemi-

cals, plus those that can be made from other fossil substances such as coal and natural gas.

It has already been mentioned that petroleum consists of a mixture of a large number of different organic chemicals. More specifically, the chemicals comprising crude oil and its products are hydrocarbons, which are largely combinations of the basic chemical elements, hydrogen and carbon.

To help in understanding the story of petrochemicals, it should be noted first that *organic* chemistry deals with the multitude of compounds based primarily on the chemistry of carbon, mostly in combination with hydrogen, oxygen, and some other elements.

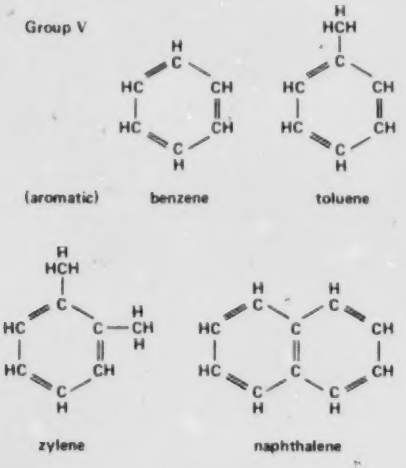
Inorganic chemistry deals generally with all the other elements found on earth, such as silicon, iron, aluminum, etc., and relates to such common and useful materials as metals, rocks, concrete, glass, water, air, salt, etc.

There is a small overlap between organic and inorganic chemistry, which are separated somewhat arbitrarily but partially for convenience. The most outstanding characteristic of organic chemistry is that there is an almost unlimited number of distinct and identifiable organic compounds that can be formed by various combinations of carbon and hydrogen, plus certain other elements. Although many of these have originated only in connection with life processes and have never been duplicated in the laboratory, there are thousands of others that have been synthesized by man either from the basic elements themselves or from the wide variety of hydrocarbons found in petroleum. In fact,

every week thousands of new unique organic chemicals are compounded, identified, characterized, and registered all over the world.

The chemist's view of the makeup of hydrocarbons is that the basic building blocks are molecules, and their composition and linkages determine the properties and special characteristics of each compound. The individual molecule of a specific material comprises in turn a special combination of the atoms of certain basic chemical elements, mainly carbon and hydrogen.

PETROCHEMICAL MOLECULES



The multitude of organic chemicals are all different even though they consist mainly of hydrogen and carbon. The importance of organic chemistry generally is that many thousands of these organic chemicals are not only necessary to life but also useful to mankind in many different ways.

The science of petrochemistry includes the controlled procedures by which specific petroleum hydrocarbon molecules—consisting of particular combinations of atoms—can be broken down, combined, or internally altered. When the individual atoms are recombined into new kinds of molecules, and these are rearranged and reconnected, entirely different substances are created with their own special unique and often useful properties.

Most of the processes of petrochemistry involve, like petroleum refinery techniques, the use of various controlled conditions of temperature, pressure, and time, plus the use of special catalysts that mysteriously stimulate and hasten the chemical reactions without becoming part of the product.

Historically, the early petrochemical developments occurred in the United States during World War I, when there were severe shortages of many chemicals critically needed for military and civilian uses. One of the most important examples was a chemical known as toluene, urgently required as a basic source material for, among other things, explosives like TNT (*tri-nitro-toluene*).

Between World Wars I and II the petrochemical industry continued to develop very rapidly. Just before World War II, petroleum refining was being undertaken on a large scale and was producing great quantities of a variety of raw hydrocarbon materials. The United States was thus at that time in an advantageous position to meet the large war-generated demands for high-octane aviation fuels, explosives, plastics, solvents, detergents,

fertilizers, and synthetic rubber, one of the most important of all. The strong incentives of a wartime economy stimulated effective research and development programs in industry to respond successfully to these demands.

One of the principal characteristics of petrochemicals generally is that they have been useful in such a wide range of different industries and consumer applications fields, such as plastics, detergents, agriculture (including fertilizers and insecticides), food processing, automobile manufacturing, building construction, paints, and textiles.

The automobile industry, for instance, has made excellent use of petrochemicals. Every car built today includes literally hundreds of plastic and other parts, coatings, and substances that are derived from petroleum.

In the textile industry many of the man-made fibers that have improved the whole character of clothing are due to petrochemical developments.

In the construction industry, widespread use has been made of petrochemicals in such areas as flooring and roofing, protective and decorative coatings, adhesives, electrical equipment, tiles, fixtures, panels, piping, and insulation.

The petrochemical industry has grown tremendously since World War II, but only a small part of this expansion can be attributed to the Nation's population growth. The increase is based on the replacement of a host of natural raw materials and derived products (such as wood, cotton, wool, and metal) by petroleum-derived materials and products, which are sometimes better suited to the

application and often available at lower costs. Many entirely new and useful substances and materials have been developed and placed on the market. An outstanding example is polyethylene, whose production has multiplied thousands of times in a 20-year period.

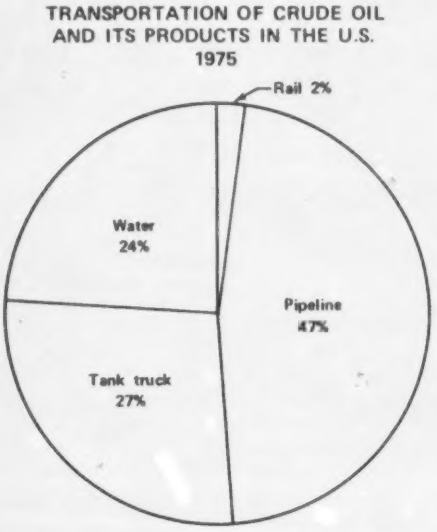
It is not an exaggeration to say that the petrochemical industry has contributed as much as any other element of our economy to a better quality of life, higher standard of living, and the overall well-being of the population. The almost endless stream of important and useful products that have emerged from this highly complex technology, when viewed in the light of the limited deposits of petroleum left on earth, leads inevitably to a sobering conclusion. If there is to be a continuation of these benefits into the future, society must consider some prompt major actions with regard to petroleum conservation, as well as effective oil exploration and recovery techniques. It may well be that petroleum is actually becoming too valuable to burn as a heat or power source.

Transportation

Unfortunately, most petroleum production in the United States and in the world at large is located in areas remote from centers of population. Hence, the transportation of crude oil to refineries and of the end products to the consumer markets has necessitated establishing extensive transportation and storage facilities. These include pipelines,

oceangoing tankers, barges, railroad tank cars, and highway tank trucks.

In its movement from the oil field to the refinery and on to the consumer, petroleum and its products may use many different combinations of these various methods of transportation. The figure shows how the total movement of domestic oil and its products is divided among the major methods of transportation.

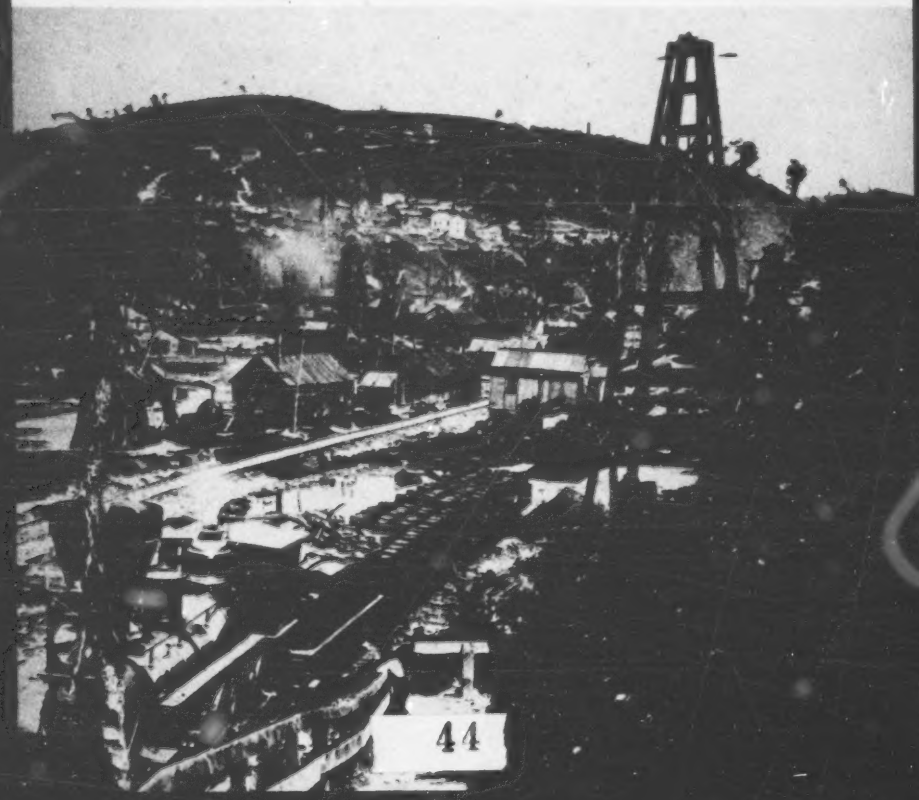


Because it is a liquid, oil is generally easier and cheaper to transport than most other energy sources except gas. One of the least expensive and most convenient methods is via underground pipeline. The first major cross-country pipeline of 177 kilometers (110 miles) was laid in northwestern Pennsylvania

only a few years after the first oil well was drilled there in 1859. Since that time, the use of this technique has steadily grown, until now the United States is crisscrossed by over 322,000 kilometers (200,000 miles) of oil pipelines (not including a much larger network of gas pipelines).

Although the initial investment in a pipeline is necessarily substantial, the overall cost of transporting the products is low, particularly when a steady flow can be maintained.

The Oil Creek Railroad near Rouseville, Pennsylvania. The first oil cars were regular flatcars on which oil barrels stood on end as shown above. The first tank car, consisting of two large wooden tanks mounted on a flatcar, did not appear until 1865, and the iron boiler tank car was not invented until 1869.



The larger the diameter of the line, the lower the shipment cost. For example, it costs less than 1¢ to send a gallon of oil from Texas to New York via large diameter pipelines.

One of the latest developments in this rapidly advancing branch of technology is the Trans-Alaska pipeline. This critical link is designed to bring oil from the North Slope of Alaska to the United States and other markets at the ultimate rate of 2 million barrels per day.

The final approval of this project was preceded and delayed by 2 years of bitter controversy and painstaking evaluation of the many environmental and economic factors involved. It is the largest such project ever financed by private industry, it will cost over $7 billion, and it has been accomplished under the most difficult imaginable conditions of climate and terrain. The completion of the pipeline in Alaska will bring this kind of technology to new levels of advancement, and set many new and impressive records.

This remarkable pipeline will snake its way above- and below-ground across 1300 kilometers (800 miles) of some of the wildest and most savagely cold country on earth, where average winter readings range down to 51°–57° below zero Centigrade (60°–70° below zero Fahrenheit). Special design features will speed the movement of warm oil through the huge 1.22-meter (48-inch) diameter pipe without melting or destabilizing the permanently frozen ground, called permafrost, which is a natural feature of the environment of that region.

During construction of the Alaska pipeline, engineers decided to blast along the Delta River floodplain in winter instead of during milder seasons in order to save downstream salmon spawning grounds from siltation.

Many new engineering advances have been incorporated into the design of the Trans-Alaska pipeline, including special heat exchangers, improved insulation techniques and built-in earthquake-proof design features. The project is one of the most monumental technical and engineering achievements in human history.

When it is necessary to send large volumes of various petroleum end products to consuming centers, batches of several different materials, such as gasoline, furnace oil, diesel fuel, etc., can be forced through the same pipeline in sequence, or "slugs", of many thousands of barrels each. Although there is inevitably some mixing of the different products at the boundaries, this effect is small compared to the total amounts being transported.

These early pipelayers were called "tong gangs" because of the tongs with which they plied their trade.

The next cheapest mode of transportation is by oceangoing tankers, which have been used extensively, ever since the first John D. Rockefeller sent a clipper ship full of Pennsylvania crude oil all the way around South America's Cape Horn to California in the early 1860s.

Particularly when land-based pipelines are not feasible or economic, tankers offer advantages as to flexibility of origin and destination, although these benefits may be somewhat offset by the need to make return trips without cargo.

The apparent fundamental economic merits of large tankers stimulated the construction throughout the world of an oceangoing fleet of about 3500 vessels. Many of these supertankers have a capacity of over 100,000 and up to 400,000 tons. However,

the drop in world oil demand following the Arab embargo of 1973 caused a substantial excess of tanker capacity, and by 1976, 15% of the fleet was idle.

Movement of crude oil and its products is also undertaken extensively by large towed barges. Although these are relatively slow, they are useful in the Great Lakes and the

This supertanker crisscrosses the seas with cargoes of crude oil and refined petroleum products.

almost 48,000 kilometers (30,000 miles) of inland waterways and canals in our country.

Railroad tank cars were at one time extensively used for long-distance handling of petroleum products, but this mode of transportation has decreased in recent years to

Bulk stations, which dealt directly with the consumer, were one of the first ways of marketing oil. Most stations carried not only kerosine and gasoline, but also axle grease, hoof oils, and floor dressing. This bulk station in Findlay, Ohio, was photographed in 1911.

only 2% of the total as shown in the chart on page 41.

Finally, there are the familiar highway tank trucks, of which there are now in the United States approximately 160,000, used mainly for local and short-distance distribution.

An essential element of the transportation of petroleum and its products is the need for adequate storage facilities, since the flow of such a wide variety of materials cannot be synchronized exactly with market demands. This need has given rise to the construction of large numbers of the familiar round oil storage tanks, usually located in groups, or "farms", near a refinery or major distribution point. Large quantities of petroleum products are also stored in underground tanks and caverns.

Chapter 5.
Looking Ahead

To look into the future of petroleum use, it is necessary first to review the remarkable changes that this unusual substance has brought to man over the past century.

Beginning in prehistoric times, man gradually found better means than his own muscles to provide the energy to do his work—first using animals, then burning wood and employing wind, rushing streams, and dammed-up water. Next came the fossil fuels—petroleum, coal, and gas—which opened up a new era of much greater energy availability and stimulated the development of all kinds of machines and engines to accomplish more and more work.

Among the nations of the world, there has been a close correlation—particularly during the last hundred years—between energy consumption, economic growth, and industrial productivity. As the Nation's energy use increased, so did its output of goods and

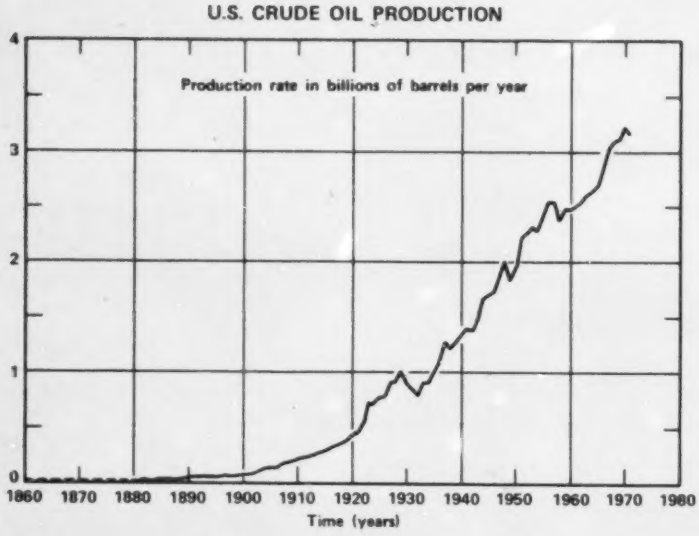
services, and this led to higher standards of living and a better quality of life. This pattern seems to point the way to the future.

Ever since oil was discovered in usable commercial quantities a little over a century ago, its most important function has been to provide energy in the form of fuel for many different purposes. Mainly these have been to furnish heat for homes, businesses, and factories, to drive machines, to generate electricity, and to provide power for automobiles, trucks, railroads, ships, and planes.

Of the machines that do 99% of U.S. work, three-fourths burn petroleum fuel, and they also depend upon other petroleum-derived products for proper lubrication, continuing reliability, and effective maintenance.

The average present-day worker using such machines can turn out six times as much in the way of goods and services as a man could 100 years ago. In such activities as agriculture and manufacturing, modern man's advantage is even more striking.

The most common unit of oil consumption is *millions of barrels per day*, which is an impressive indication of the extravagant rate at which petroleum is now being used. The United States accounted for about 17 million barrels on an average day in 1975, and this represents about 30% of the world total. This figure seems even more stupendous when compared to the grand total of 2000 barrels of crude oil produced during 1859, the year in which the first U.S. oil well was drilled. The graph on page 50 shows the impressive increase in annual crude oil production in the



United States from 1920 to 1970, after which the total national output began to decline.

But even more machines, energy, and electric power will be needed in the future for industry, agriculture, transportation, and business operations, to keep up the steady pace toward a higher standard of living for a larger proportion of the world's population, both here and abroad. The future total demand for petroleum will thus continue to expand through the extension of mechanized operations and other petroleum-related benefits to less fortunate people who now possess relatively fewer machines and limited energy resources, especially in other parts of the globe.

Another specific need for more energy will be the large amounts of power to keep

the environment clean and reduce pollution. Most environmental improvement methods require substantial quantities of energy, often in the form of electric power.

Apart from its many fuel and other related applications, petroleum will also be responsible, within a few short years, for 98% of all the valuable organic chemicals so prized in our society. As these useful petrochemical products are increasingly used all over the world, the demand for the crude oil source material will undoubtedly continue to rise.

As a result of all these factors, U.S. oil consumption is forecast to double in the final quarter of the century, a prospect that brings the Nation up against some hard sobering facts.

Probably the grimmest truth of all is that the United States until 1975 the world's number one petroleum producing nation, has finally been overtaken by the U.S.S.R., which had held the number two position for many years. A further unpleasant reality is that during 1973–1975, when energy pinches were evident almost everywhere in the world, the U.S. domestic production of oil dropped 10%, continuing a steady decline begun in 1970. During the same 2 years, the world price tripled, causing widespread economic upheaval.

There is an inevitable painful result of the continuing rise in demand for petroleum in the United States, coupled with a decrease (or at best a leveling out) in domestic production in the foreseeable future. It is the need to import increasingly large quantities from

abroad at elevated prices unless satisfactory substitute energy sources can be developed.

Oil imports in 1975 were at an average of 6 million barrels a day, or 38% of our total consumption. If present demand trends continue, U.S. imports by 1985 will probably be 15 to 18 million barrels a day, substantially more than half of our total usage.

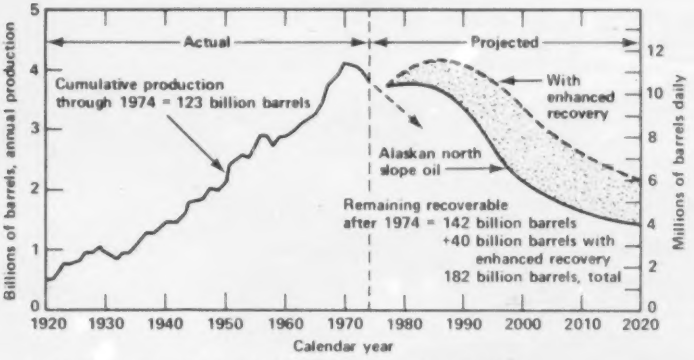
A variety of serious economic and monetary problems may occur during the 1975–1985 decade if the Nation is forced to import such a large percentage of its most critical commodity at inflated prices. The national defense implications are especially ominous, considering the importance of petroleum products of all kinds to the military machine.

These are some of the unfortunate facts of life that our country faces as it begins its third century. It may well be that drastic changes in our life style, standard of living, and conservation practices will be necessary. Perhaps traveling cheaply, enjoying cheap electricity, and using cheap home heating can no longer be taken for granted as fundamental elements of American democracy.

The chart on page 53 presents a summary of the best available data on past and projected production of crude oil in the United States. It is significant that roughly 80% of the Nation's total original recoverable petroleum deposits are expected to have been used up in the 67 years between the Great Depression of the 1930s and the end of this century.

The world's oil-producing regions are shown in the map on page 54. The United

ACTUAL AND PROJECTED DOMESTIC OIL PRODUCTION, U. S.



In this figure, domestic oil includes crude and natural gas liquids

States is estimated to have only 8% of the world's known total, whereas the Middle East area possesses 62%, of which 25% is in the nation of Saudi Arabia alone.

In summary, the most critical commodity during the final quarter of the 20th century for the United States and many other countries will be petroleum. While reasonable conservation techniques must be established and enforced, it is important to recognize that no amount of conservation (which has already been practiced by industry and many states for decades) can possibly make available the vast amounts of petroleum required to meet all the anticipated demands as outlined above.

Thus, the clear and urgent message of today in the field of petroleum is to find more of it, to process it for carefully planned uses, and at the same time to explore other alternatives and options for suitable substitute energy sources. This is exactly what the

Offshore and onshore sedimentary basins and petroleum producing areas of the world.

Energy Research and Development Administration (ERDA) is doing in cooperation with various industries. Two of the most important specific areas of investigation are described briefly in the chapter that follows.

Chapter 6.
New Programs

New energy technologies are urgently needed in order to maintain and improve the Nation's security, economy, and life-style. Major efforts by industry and Government are required now, even though significant results may not emerge for years to come.

To ensure flexibility and to allow for varying degrees of success in research and development programs, overall planning must provide a number of different choices, or alternatives. This is why the National Plan for Energy Research, Development and Demonstration, formulated by the Energy Research and Development Administration, covers a wide range of technologies, including those related to fossil fuels, nuclear energy, geothermal energy, and solar energy, as well as conservation techniques.

Since our Nation is blessed with large coal deposits (over 50% of the world's known

reserves), some of the most promising development activities now under way are to develop coal liquefaction processes that would yield liquid fuels to substitute for those now being refined from petroleum.

Included in the near-term activities planned by Government and industry in oil technology are large programs in two significant fields outlined below. These are techniques for the enhanced recovery of oil still trapped in oil fields that have been partially exhausted, and oil production from oil shale, a special type of rock found in vast quantities in the western part of the United States.

Enhanced Recovery

It is estimated that two-thirds of all the oil discovered so far in the United States still remains in the ground after producing wells have brought up the one-third that can be recovered by conventional methods.

If satisfactory methods could be developed to bring this trapped oil to the surface, there would theoretically be enough to last another half-century at the current rate of consumption. But the technology to reach this objective at a reasonable cost is not yet available.

A great amount of scientific research has been devoted to the techniques of enhanced recovery, which include a variety of procedures used to salvage oil that cannot be readily pumped to the surface. The methods developed have taken a number of forms, depending upon conditions and circumstances at each individual oil field.

In the most common situation, water is pumped into an oil reservoir and "sweeps" a sizeable portion of the remaining oil toward the producing wells. This waterflooding technique has been employed in over 90% of all U.S. oil fields.

In some instances, detergents, similar to those used at home for washing clothes and dishes, are pumped into "played out" wells in an attempt to wash out the remaining oil in the underground reservoir.

Under other conditions, where a tar-like oil may be trapped inside an underground rock formation, the rock has been set on fire, or heated by steam, in order to thin the oil and facilitate its movement toward the existing wells.

In a method called hydraulic fracturing, widely used in the petroleum industry, underground channels for oil flow are opened up by the force of high-pressure fluids, which contain "propping agents" to keep the expanded channels propped open.

A procedure that has had limited success is carbon dioxide flooding, whereby carbon dioxide gas is forced into the petroleum reservoir where it dissolves in the oil, reduces viscosity, and forces the oil toward the outlet wells.

Solvents like kerosine or dry-cleaning fluids have been used under certain conditions to dissolve the oil out of the rock. These solvents are very expensive, although they can be recovered, refined in the field, and recycled.

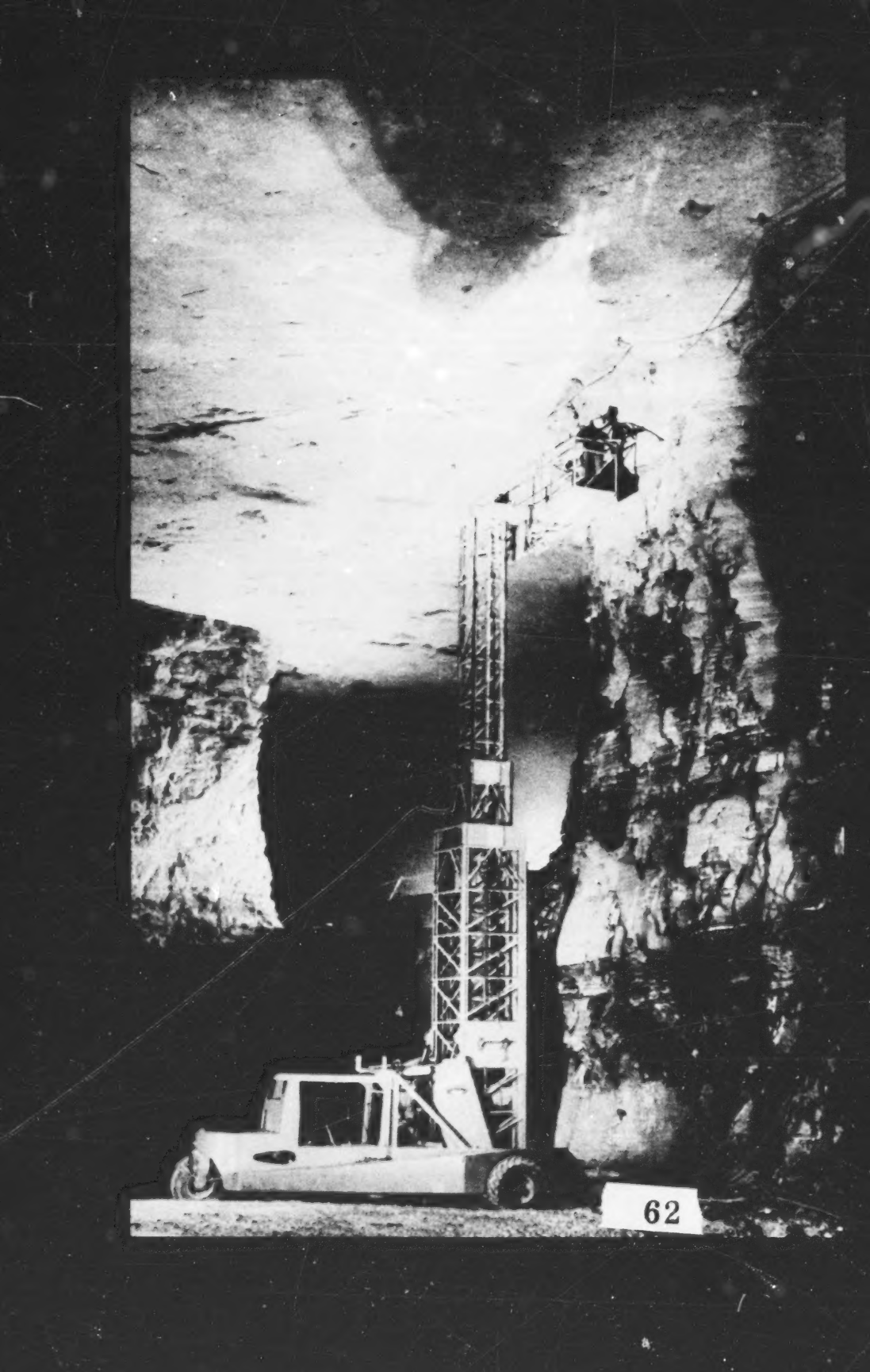
There are several large cooperative Government-industry oil recovery projects now under way, although much more development and testing remains to be done, even after a half-century of work in this field of technology. The results of these efforts are necessarily slow in coming, and it may be 5 to 10 years before substantial amounts of oil recovered by these techniques will reach the consumer. However, the amount of oil available is immense and well worth the effort.

Oil from Shale

Oil shale is a fine-grained rock containing organic material that makes it look something like chocolate marbling in ice cream. Geologists believe that in the United States it was formed 30 to 60 million years ago in a wide area of lakes once covering a now sparsely settled and rugged territory of about 44,000 square kilometers (17,000 square miles) in Wyoming, Utah, and Colorado.

The organic matter in the rock, called kerogen, can be extracted from shale and converted into high-grade oil by several different methods. The first steps in most of these processes are mining and crushing the rock, and these are followed by heating to about 480°C (900°F). The resulting material can be further refined and processed, like petroleum, into a wide variety of products.

Historically, shale oil was first recovered commercially from a deposit of shale rock found in Scotland, where such processes were successfully undertaken as early as 1850 and continued for over a century.



If only one-third of the estimated existing shale oil in the United States could be recovered, it might amount to about 600 billion barrels, which is more oil than is believed to exist in all of Saudi Arabia.

While this total available quantity seems enormous in the light of our current energy shortages, the eventual cost of recovering it in large quantities is estimated to be very high. As to plant costs, a $10 billion* capital investment is estimated as necessary for a facility to produce 50,000 barrels a day — only a small fraction of current total U.S. crude oil consumption.

The Federal Government owns 80% of the known oil shale land in the United States, but has encouraged private enterprise to develop methods of shale oil recovery, and at the same time helped to plan for minimal environmental degradation of the land.

The processing of rich oil shale may yield about 95 liters (25 gallons) of oil per ton of rock, but unfortunately the leftover waste material occupies 10% more volume than the original rock. From an environmental viewpoint, one acceptable method of disposal of this processed rock, which looks and feels like a black sandy soil, might be to place it in the deep canyons that are common in the oil shale area. With proper treatment, it has been shown that some kinds of grasses and plants will grow on this type of ground.

*1975 dollars.

In this oil shale mine in Colorado, heights of more than 21 meters (70 feet) may be reached with this mobile work platform and extendable boom.

Another possible disposal method would be to return the waste material to the mine, although this procedure poses difficult economic, technical, and environmental problems.

Over a 30-year period, it is estimated that 30,000 to 32,000 hectares (75,000 to 80,000 acres) of land, including that needed for communities of people working at the plant, would be required for a 1-million-barrel-per-day shale oil facility.

A serious problem in current shale oil recovery processes is the requirement for vast quantities of water—about 7.5 to 19 liters (2 to 5 gallons) for every gallon of recovered oil depending on the details of the process. A large portion of this water will be locked into the spent material and hence not available for recycling. The limited water resources of the particular geographical area involved would thus be badly strained to support large shale oil recovery operations.

Another technique for recovering shale oil, currently being investigated by ERDA and several private firms, involves crushing and heating the rock before mining operations are begun. This is called the "in place" or "in situ" method. More experimentation is needed to determine the ultimate usefulness of this approach.

In summary, oil shale has a great theoretical potential for the United States as a future source of energy and valuable chemicals. But the mammoth economic, technical, and environmental problems inherent in the tapping of these huge reserves may prevent them from being used.

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Dr. Eaton has written articles in a number of technical fields, including several related to various aspects of energy. For ERDA, in addition to this booklet, he has written "Geothermal Energy", "Solar Energy", "Energy Technology", and "Energy Storage".

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A word about ERDA . . . .

The mission of the Energy Research & Development Administration (ERDA) is to develop all energy sources, to make the Nation basically self-sufficient in energy, and to protect public health and welfare and the environment. ERDA programs are carried out by contract and cooperation with industry, university communities, and other Government agencies. Its programs are divided into six major categories:

- CONSERVATION OF ENERGY — More efficient use of both existing and new sources of energy in industry, transportation, heating and cooling of buildings, and the generation of electricity, together with more efficient transmission of energy.
- FOSSIL ENERGY — Expansion of coal production and the development of technologies for converting coal to synthetic gas and liquid fuels, improvement of oil drilling methods, and development of techniques for converting shale deposits to usable oil.
- SOLAR, GEOTHERMAL, AND ADVANCED ENERGY SYSTEMS — Application of solar energy to heat and cool buildings and development of solar-electric power, conversion of underground heat sources for electricity and industrial heat, and development of hydrogen fusion for generating electricity.
- ENVIRONMENT AND SAFETY — Research, evaluation, and control of health, safety, environmental, and socio-economic impacts of all phases of any energy-producing cycle from extraction of raw materials to power generation, transmission, and waste disposal.
- NUCLEAR ENERGY — Expansion of medical, industrial and research applications; advancement of reactor technologies for generating electricity; and production of nuclear materials for civilian needs.
- NATIONAL SECURITY — Development, production, and testing of nuclear weapons and attention to such related issues as safeguards and international security matters.

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